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Percutaneous Nephrolithotomy in the Prone and Prone-Flexed Positions: Anatomic Considerations*

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Abstract

Objectives: Percutaneous nephrolithotomy is commonly performed in the prone position. Knowledge of renal anatomy and the relationship of adjacent organs is essential to minimize patient morbidity and iatrogenic organ injury. We present the anatomical basis for a prone-flexed modification to patient positioning and review the advantages and disadvantages of alternate positions.

Methods: Triphasic computed tomography was conducted with the patient in supine, prone, and prone-flexed positions, and an anatomical survey was conducted. A 30° angle was used to approximate the plane of nephrostomy access and the risk of organ injury.

Results: For upper pole punctures, the liver and spleen were more medially situated, and thus more likely to be injured with supine positioning, compared with either prone or prone-flexed positioning ($p < 0.001$). In contrast, for lower pole punctures, the colon was more medially situated in the prone and prone-flexed positions compared to supine ($p < 0.001$). With prone-flexed positioning, the left kidney was displaced lower than the right in 92.3% of cases. The prone-flexed modification increased the distance from the posterior iliac crest to the 12th and 11th ribs by 2.9 and 3.0 cm, respectively ($p < 0.001$). If access was performed in the most superior calyx, this would have converted an upper pole access above the 11th rib to one above the 12th rib in 5 of 11 patients (45.5%).

Conclusions: Prone-flexed positioning is a simple modification that provides improved access to the upper pole and more mobility for lower pole percutaneous nephrolithotomy. This position is well tolerated and has several advantages over other patient positions, including the supine position.

Introduction

Since the introduction of percutaneous renal surgery for stone disease by Fernstrom and Johansson in 1976,[1] there has been a proliferation of case series addressing various aspects of the technique. Initially, access for percutaneous nephrolithotomy (PCNL) was obtained by a radiologist; however, the senior author first started performing his own access in 1981. Although the prone technique was the standard approach to the kidney, it was generally agreed that this technique may not be optimal for all patients, particularly the morbidly obese or those with respiratory compromise. Several modifications have been reported, including the lateral decubitus position,[2–4] modified lateral,[5] reverse lithotomy,[6] and split-leg[7,8]; however, most of these have fallen out of favor. Recently, there has been a resurgence of interest in supine PCNL performed in the so-called Galdakao-Modified Supine Valdivia position.[9] Potential advantages and disadvantages to each of these techniques are outlined in Table 1. The purpose of this review is to outline the implications of performing PCNL on patients in various positions and to provide an anatomical explanation for known complications associated with the procedure. Finally, we describe our technique in detail as well as the anatomical rationale behind it.

Materials and Methods

Description of PCNL in the prone-flexed position

Retrograde pyelogram and choice of calyx. With the patient intubated under general anesthesia in the supine

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*A video demonstrating this technique is available on the enclosed CD ROM and online at www.liebertonline.com/end.

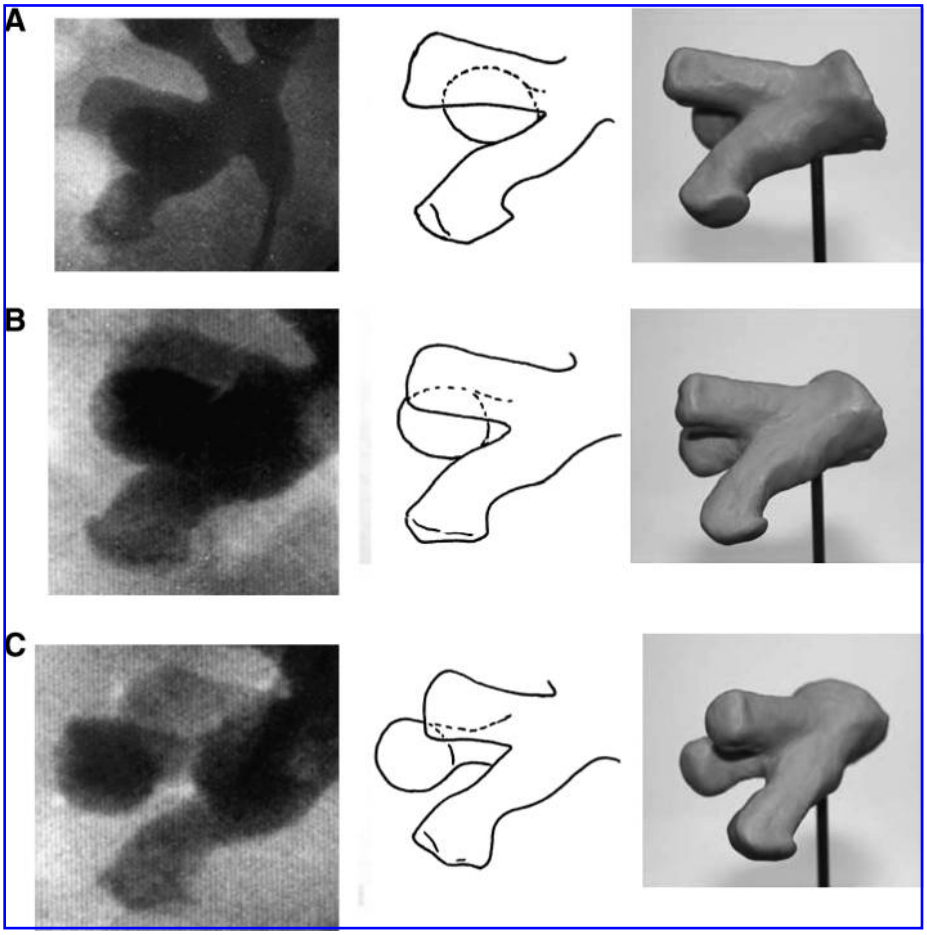

FIG. 1. Three-dimensional model of renal collecting system. Anteroposterior (**B**) and oblique (**A, C**) views of the lower pole calyces are demonstrated in a supine patient using the C-arm image intensifier. The posterior calyx is dependent, filling with the more dense contrast material. Anterior calyces, containing both urine and contrast, are paler.

position, flexible cystoscopy is performed. A 5F Flextip ureteral catheter with a terminal side hole (Cook Urological) is passed into the collecting system. Urine is completely aspirated and replaced with radiographic contrast to identify all calyces. A C-arm image intensifier is used to examine the anatomy of the collecting system and the position of all stones. Four images are captured: a scout image to identify all calculi, an anteroposterior, and two obliques. These images help create a mental three-dimensional picture of the calyceal anatomy, serve as a useful teaching tool, and can be referred to during the procedure (Fig. 1). This allows one to choose a posterior calyx that will allow access to the majority of the stones. Using the oblique images, posterior calyces are identified by the presence of denser contrast medium within them, while lower density contrast mixed with urine is displaced anteriorly. A ureteral occlusion balloon is inserted over a guidewire, positioned at the uretero-pelvic junction, and secured externally to a Foley catheter. A three-way valve is attached and connected to a 10 mL syringe and i.v. tubing leading to a bottle of contrast.

Renal puncture and dilatation of the tract. The patient is then placed in the prone position, and the table flexed 30° to 40° to open the space between the 12th rib and the posterior iliac crest (Fig. 2). The flank is prepared and draped with an adhesive neurosurgical drape containing a drainage pouch. The C-arm is draped and used to identify the previously chosen calyx. Because of the change to prone position, the posterior calyx is now less dense as the heavier contrast medium flows into the anterior calyces (Fig. 3). In the prone position, the posterior calyces move in the opposite direction to the image intensifier of the C-arm. As the C-arm is rotated toward the operator the posterior calyces move away, and shorten. With the C-arm rotated 30° from the vertical, toward the operator, the posterior calyx is viewed end-on. The previously chosen posterior calyx is then identified and an 18-gauge Trocar needle is used to puncture the calyx at the center of the papilla. The needle is inserted and advanced along the line of the X-ray beam. The C-arm is periodically rotated away from the operator, to assess the depth of the needle. To minimize radiation exposure to the surgeon's hands, the needle is held in a long Kelly forceps, aligned with the calyx under fluoroscopy, and advanced during expiration without fluoroscopy (Fig. 3). Once the calyx is entered and a free flow of contrast obtained, an Amplatz Extrastiff or Superstiff guidewire is passed down the needle into the collecting system. Because of the presence of the occlusion balloon, we do not attempt to pass the guidewire down the ureter, although this may occur. A small-depth gauge ring on the needle is adjusted to skin level to mark the depth between the skin and the collecting system. Knowledge of this measurement reduces radiation exposure during insertion of the fascial dilators and nephrostomy tract dilating balloon. The tract is then serially dilated to 10F, using fascial dilators, followed by a 10F dual lumen catheter through which a safety wire is inserted and secured to the

FIG. 2. Operating room setup and patient positioning. The prone-flexed modification increases the area for puncture and flattens the flank, decreasing obstruction of the nephroscope by the buttocks. Note the widening of the area between the lines drawn on the flank.

skin. The tract is dilated to 30F with a nephrostomy tract dilating balloon over which an Amplatz sheath with a 30F inner diameter is passed.

Anatomical implications of patient positioning

During 12 successive PCNLs, with the patient anesthetized in the prone position, bony landmarks were identified fluoroscopically. A line was drawn on the flank at the midway point between the spinous processes and the lateral border of the abdominal wall. This plane closely approximates the line of puncture in the majority of patients. Measurements were made along this line to calculate the distance from the posterior iliac crest to the 12th and 11th ribs as well as the distance from the most superior point of the renal collecting system to the bottom of the 11th rib. These measurements were repeated with the patient in the prone-flexed position.

Abdominal triphasic computed tomography (CT) scans were conducted on 16 patients with slice collimations of 1.3 mm in the prone, supine, and prone-flexed positions. A 45° bolster was used to replicate prone-flexed positioning used during PCNL. Measurements were made from digital images using ClearCanvas 1.2 software (Fig. 4). To replicate the angle of renal puncture, and determine the relative location of adjacent organs to the nephrostomy tract, a line was drawn 30° to the vertical midline and anterior renal surface at the level of the upper and lower pole calyces using bony landmarks. The angle that the liver, spleen, and colon deviated from the proposed tract was recorded.

Statistics

Data were analyzed using Chi-square analysis, paired *t*-tests, and repeated measures analysis of variance to compare data sets where appropriate. Statistically significant differences were considered at two-sided, $p < 0.05$ using the SPSS 16.0 statistical package.

Results

Prospective anatomical data were obtained for 16 patients using triphasic axial CT with images acquired in the supine, prone, and prone-flexed positions (Table 2A). For upper pole punctures, the liver and spleen were more medially situated, and thus more likely to be injured, when the patient was positioned supine than when the patient was in the prone or prone-flexed positions ($p < 0.001$). In contrast, for lower pole punctures, the colon was more medially situated in the prone and prone-flexed positions than when the patient was supine ($p < 0.001$). On axial CT imaging, there was one left-sided retro-renal colon that was at risk of injury from nephrostomy tract insertion. In this small series, no other organ came within

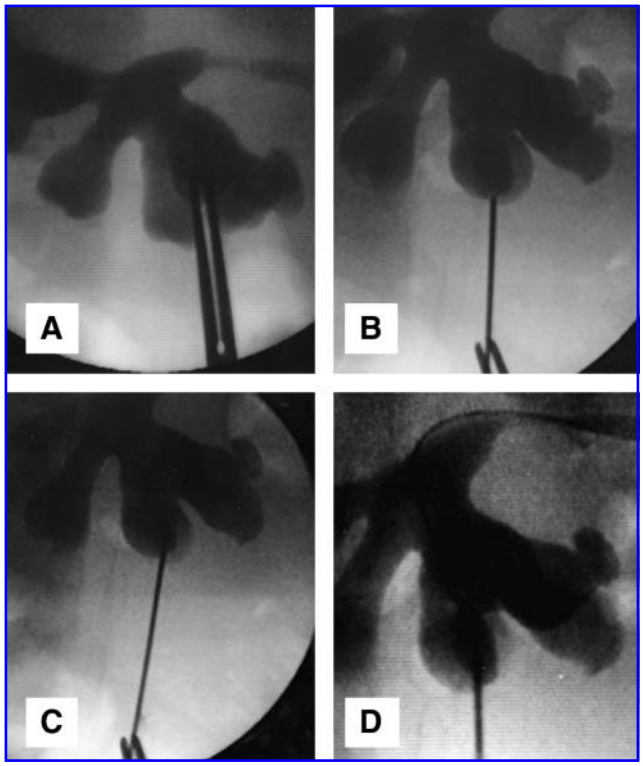

FIG. 3. Puncture of a posterior lower pole calyx. Contrast density is less in the posterior calyces when the patient is in the prone position. The depth of the needle tip can be followed by rotating the C-arm away from the operator. (**A**) Needle end-on. (**B**) Needle short of calyx. (**C**) Needle entering calyx. (**D**) Working wire down the ureter.

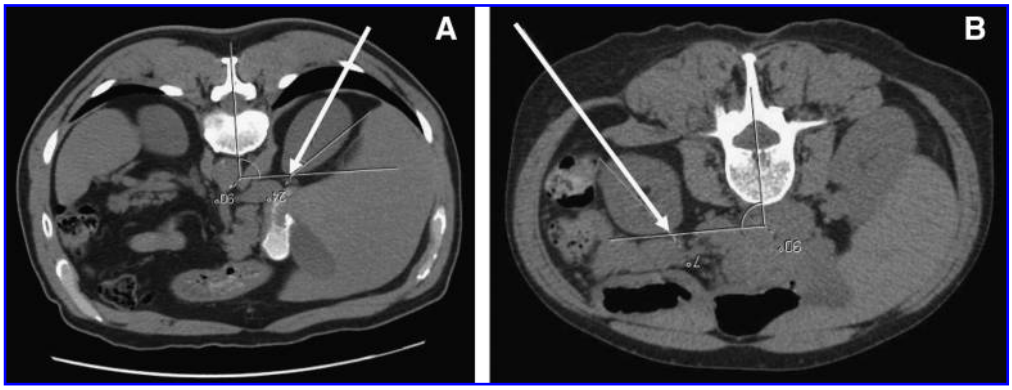

FIG. 4. Prediction of organ injury based on axial computed tomography. (**A**) Upper pole puncture risks injury to the lung, liver, and spleen. (**B**) Lower pole puncture risks injury to the colon.

5° of the simulated nephrostomy tract in the supine, prone, or prone-flexed positions.

There was caudal movement of both kidneys in the prone and prone-flexed positions. In the supine position, the left kidney was lower than the right 30.8% of the time, compared to 55.6% in the prone and 92.3% of cases in the prone-flexed positions ($p = 0.003$). Data from two patients were not considered (one left partial nephrectomy and one left nephrectomy).

In 12 patients, operative measurements were made, utilizing bony landmarks with the patient prone, and then after flexing the table 40° (Table 2B). In the flexed position, there was significant lengthening of the flank, increasing the area available for needle puncture. The distance between the posterior superior iliac crest (PSIC) and the 12th rib increased by 2.9 cm (32.6%, $p < 0.001$) and the distance between the PSIC and the 11th rib increased by 3.0 cm (23.1%, $p < 0.001$). The degree of inferior displacement of the most superior margin of the upper pole calyx in relation to the 11th rib was measured for 11 patients. The upper calyx moved caudally by an average of 1.5 cm (range 0 to 2.5 cm) after a change in patient position ($p = 0.002$). It was estimated that this would result in a 45.5% fewer supra-11th rib punctures if access was performed into the most superior calyx.

Discussion

Anatomic considerations: renal axis and mobility

Prone positioning for PCNL gained popularity during the early 1980s and rapidly became the standard approach, as it was felt that puncture of the flank along the avascular plane of Brodel provided the safest access to the kidney.[10,11] Initially, a direct calyceal puncture was not considered important. Several modifications in patient position have since been proposed with advantages and disadvantages to each (Table 1). Knowledge of renal and retroperitoneal anatomy is essential to perform the procedure with minimal patient morbidity and low risk of iatrogenic organ injury.

The kidneys lie in the retroperitoneum with the psoas muscle lying postero-medially, which results in the long axis being deviated so that the upper pole is more medial in the coronal plane. The upper pole is also closer to the posterior abdominal wall and more densely attached to Gerota's fascia.[12] The lower pole is more anterior and freely mobile.

Advantages and disadvantages of the prone position

At present, the majority of PCNLs are still carried out with the patient in the prone position, with retrograde access and placement of a ureteral catheter or occlusion balloon under fluoroscopic control. This initial procedure can be performed with the patient either supine or prone. If performed while the patient is supine, it is necessary to position and drape the patient twice, prolonging operating room time.[13,14] By commencing the procedure in the prone position immediately after induction of general anesthesia, the patient still requires repositioning, but is only draped once.[15] A split-leg modification can facilitate access to the external genitalia, for simultaneous antegrade and retrograde approaches.[7,8] In the prone position it may be difficult to access the anteriorly displaced ureteric orifices for the retrograde study. Additionally, identification of the posterior calyces, especially in obstructed systems, may be difficult because less dense urine will float on top of contrast, rendering them invisible. For this reason, it is our preference to begin the procedure with the patient supine.

Prone positioning for PCNL allows access to the entire flank, with a wide choice of access sites, especially when multiple accesses are required. Although still possible in the supine position, upper pole access is significantly easier when the patient is prone. An upper pole puncture has many advantages, including the ability to work down the renal axis, with minimal torque, and consequently a reduced risk of hemorrhage. Selection of an upper pole calyx also facilitates access to multiple lower pole calyces with a single tract. In contrast, from the lower pole, observation of the upper calyces with a rigid nephroscope is rarely possible. Upper pole puncture is indicated in obese patients, patients with staghorn calculi, or stones in a horseshoe kidney. Finally, dilatation into the upper pole is easier, because of more adherent attachments to Gerota's fascia limiting renal mobility, while the more mobile lower pole is free to rotate along the line of the nephroscope. Despite these advantages, many authors still prefer a lower pole puncture with the reassurance that this approach will avoid thoracic complications.

The prone-flexed modification that we describe provides several additional advantages over the traditional technique. First, the working distance between the PSIC and the 12th rib is further increased (Fig. 2). In addition, we have shown that when in this position, the kidneys are displaced inferiorly in

Table 1. Summary of Options for Patient Positioning

	Technique	*Advantages*	*Disadvantages*	*References*
Prone	• Patient is prone with a padded role under the thorax to facilitate ventilation	• Wide field for posterior puncture • Easy access to the avascular line of Brodel • Wide space for instrument manipulation • Easiest access to upper pole • Renal pelvis is dependent with easier access to mobile stones	• Patient repositioning prolongs OR time • Difficult in obese patients • Risk of respiratory or CV compromise • Theoretical risk of ocular complications	10, 11, 15, multiple reports not referenced
Prone-flexed	• Patient is prone, with a padded role under the thorax to facilitate ventilation • Flexed at the waist 30°–40° • Knees are flexed 15°	• Similar advantages to prone position • Further increased working space • Flattened flank decreases instrument conflicts with buttock • May convert supra-11th to supra-12th or supra-12th to infracostal access	• Similar disadvantages to prone position • Extra padding needed because of head-down position • May increase airway pressures	
Reverse lithotomy	• Patient is prone with legs in stirrups with padding • Legs are abducted and the lower end of the OR table is dropped	• Similar advantages to prone position • May perform nephroscopy and ureteroscopy without patient repositioning	• Similar disadvantages to prone position • Theoretically applicable to male patients (no published reports)	6
Prone split-leg	• Patient prone, with the genitalia at the bottom of the OR table • Legs on padded adaptors and abducted up to 45°	• Similar advantages to prone position • May perform nephroscopy and ureteroscopy without patient repositioning	• Similar disadvantages to prone position	7, 8
Lateral decubitus	• Patient in lateral decubitus with no break in the OR table	• Familiar to urologists who perform open renal surgery • Useful in morbid obesity or severe kyphoscoliosis • May perform nephroscopy and ureteroscopy simultaneously	• Patient repositioning is required • Fluoroscopy is technically limited, particularly in morbidly obese patients	2, 3, 4
Modified lateral "Barts technique"	• Patient in lithotomy with ipsilateral pelvis elevated 45° • Shoulders rotated to be perpendicular to the OR table • Ipsilateral leg is flexed and adducted, contralateral leg is fully abducted	• May perform nephroscopy and ureteroscopy without patient repositioning • Less CV and respiratory effects than prone • Improved access to flank compared to supine	• Requires significant patient mobility • Not suitable for patients with MSK deformities • Fluoroscopy is technically limited, as with lateral	5
Supine/GMSV	• Originally performed with the patient supine and the ipsilateral leg fully extended • A 3-L saline bag is placed under the ipsilateral flank • GMSV includes modified lithotomy position with extension of the ipsilateral leg and abduction of the contralateral leg	• May perform ureteroscopy and nephroscopy simultaneously • Patient repositioning is unnecessary • Improved surgeon comfort • Theoretically reduced radiation exposure • Stones may spontaneously evacuate at calyx of entry because of dependent drainage • Fewer CV and respiratory effects • May be performed without endotracheal intubation	• Instrument movement is limited by the OR table • Pyelocalyceal system is collapsed, impairing visibility • Upper pole puncture is more difficult • Many calyces are dependent and collect fragments • Placement of multiple tracts is difficult, limiting use in staghorn calculi • Longer OR times when treating staghorn stones • Ventilation may be impaired in morbidly obese patients • May be associated with higher transfusion rates	9, 13, 14, 25, 26, 27, 28, 29, 30, 31, 32

CV = cardiovascular; GMSV = Galdakao-Modified Supine Valdivia; OR = operating room; MSK = musculoskeletal.

Table 2A. Three-Phase Computed Tomography Data Conducted in Supine, Prone, and Prone-Flexed Positions

	Supine	*Prone*	*Prone-flexed*	p
Effect of body position on retroperitoneal anatomy (n = 16)				
Relative organ position				
Liver	24.0° ± 10.8	29.4° ± 13.9	32.5° ± 13.3	<0.001
Spleen	25.3° ± 12.0	28.8° ± 1.7	32.9° ± 16.0	0.001
Colon (right)	49.0° ± 8.6	40.8° ± 10.4	38.3° ± 12.3	<0.001
Colon (left)	51.4° ± 14.8	43.9° ± 4.7	47.7° ± 18.1	<0.001
Left kidney lower than right	30.8%	55.6%	92.3%	0.003

Organ position is relative to a theoretical nephrostomy tract, 30° from the vertical midline.
Data presented as mean ± standard deviation.

the retroperitoneum. This effect is most pronounced with the left kidney, which was lower than the right in 92.3% of cases. Because of this modification, a supra-11th rib access may be converted to a supra-12th rib or a supra-12th to an infracostal access. Finally, the flank is significantly flattened, eliminating interference from the buttock during lower pole access (Fig. 2).

Prone positioning also carries some disadvantages. Maintaining anesthesia can be difficult, particularly in obese patients or those with cardiovascular or respiratory compromise. We have also found that the prone-flexed modification may further increase airway pressures in obese patients, necessitating a reduction in patient flexion. We have not found it necessary to revert to conventional prone positioning. Additionally, in this position, there is a theoretical risk of blindness, because of increased intraocular pressure resulting in ischemic optic neuropathy. This is rare and only reported during spinal surgery, especially with prolonged operating room times in excess of 450 minutes.[16] We are unaware of any cases following PCNL.

Complications of PCNL

Organ injury. The position of the kidneys within the retroperitoneum is dynamic, changing with both respiration and body position. Our data demonstrate that when the patient is positioned in the prone or prone-flexed positions, the spleen and liver rotate laterally, away from the kidney and nephrostomy tract, compared to when the patient is positioned supine. This would make it less likely that either of these organs would be injured with a puncture 30° from the vertical. Similar movements were previously reported by Ball et al.[17] An anatomical study using magnetic resonance imaging reconstruction reaffirmed the preference for more medial puncture to avoid iatrogenic injury to the spleen and liver.[18]

Several studies have utilized both CT and magnetic resonance imaging to estimate the relative risk of iatrogenic organ injury during renal puncture. Organs at risk from upper pole puncture include the liver, spleen, and pleural space.[18–20] In contrast, the colon is most at risk from lower pole access.[21] Risk of organ injury varies considerably among published reports. In one study, the predicted risk of injury to the liver or spleen with upper pole puncture was approximately 15%, but decreased to zero by changing body position from supine to prone.[19] In contrast, the same group found that the incidence of retrorenal colon was 4.7% in the prone position and 1.9% in the supine position.[22] In a study of axial and multiplanar reformatted CT scans, Tuttle and coworkers demonstrated that axial CT scans may dramatically overestimate the risk of injury. The risk of organ injury associated with lower pole puncture on axial CT was 6.0% in the supine position versus 15.1% with the patient prone; however, for oblique parasagittal CT reconstructions, the risk was decreased to 3.0% and 0%, respectively.[21] These findings are more in keeping with clinical series demonstrating low rates of organ injury. The lack of a standardized approach may also account for the variability in these reports. In the largest clinical series, the rate of bowel injury was 0.06% of almost 1600 procedures, with no cases of splenic or liver injury.[15] Others have reported similarly low rates of organ injury[10,11,23]; however, in some series, access was obtained in the radiology suite.

Although supine PCNL has recently gained popularity, we continue to be strong advocates for the traditional approach. Valdivia Uría et al and Falahatkar et al state that the colon "floats away from the kidney when the patient is in the supine position."[9,14] Our CT studies did demonstrate that the colon was more medially situated and theoretically more prone to injury in the prone and prone-flexed positions compared with supine. However, the colon is attached laterally to the peritoneum of the side wall of the abdominal cavity at the level of the kidneys and movement is minimal. The more lateral approach of the supine position would therefore still be more likely to result the rare complication of colonic injury.

Table 2B. Change in Flank Measurements with the Prone-Flexed Modification

	Prone (cm)	*Prone-flexed (cm)*	*Distance gained (cm)*	p
Effect of prone-flexed position on flank access (n = 12)				
PSIC → 12th rib	8.9 ± 2.2	11.8 ± 2.5	2.9	<0.001
PSIC → 11th rib	13.0 ± 2.2	16.0 ± 2.1	3.0	<0.001
Superior calyx → 11th rib	1.5 ± 1.6	0.0 ± 0.9	1.5	0.002

Data presented as mean ± standard deviation.
PSIC = posterior superior iliac crest.

Thoracic complications. The risk of pleural injury is of considerably greater concern. In the majority of cases, the diaphragm inserts onto the 12th and 11th ribs with the pleural reflection running horizontally and crossing the midpoint of the 12th rib. The risk of pleural injury is therefore related to the level of renal puncture and is most common with upper pole access. Significant complications include pneumothorax, hydrothorax/hemothorax, and empyema. In a study by Munver and coworkers, the overall complication rates ranged from 4.5% for subcostal access to 9.7% above the 12th rib and 34.6% above the 11th rib. The incidence of thoracic complications was 23.1% above the 11th rib, but dropped to just 1.4% above the 12th rib.[24] Our data demonstrate that a prone-flexed modification to patient position results in inferior displacement of the kidneys, especially the left kidney, which could result in fewer thoracic complications (Table 2B).

Hemorrhage. Normally, the upper pole of the kidney is more medially and posteriorly located than the lower pole. Consequently, an upper pole posterior calyceal puncture lateral to the paraspinal muscles will result in access being more in line with the axis of the kidney. This will result in less torquing of the kidney to reach the lower calyces and less chance of parenchymal splitting and bleeding. An angled tract that is not in line with the infundibulum or renal axis or a puncture of the lateral calyces will require more torque to reach the stone, resulting in unnecessary bleeding and increased transfusion rates. Choice of the appropriate percutaneous tract through a posterior calyx in line with the infundibulum will allow the operator to achieve a transfusion rate for PCNL of approximately 1%.[15] In our recent series of 180 prone-flexed PCNL, no patients required a blood transfusion.

Supine positioning

In an attempt to overcome some of the difficulties associated with prone positioning, there has been a resurgence of interest for PCNL performed in the supine position. The first report on supine PCNL, by Valdivia Uría et al in 1998, included 557 patients.[9] These authors expressed a preference for puncture of anterior calyces, with low complication rates; however, transfusion rates were not reported. Other authors have similarly found that puncture of anterior calyces is often necessary in the supine position.[13,25] A review of all studies published to date demonstrated an overall transfusion rate of 4.5% (range 0–20%) with PCNL performed in the supine position.[13,14,25–32] This may be caused by renal shear, as puncture of anterior calyces would result in more manipulation. In the supine position, stone fragments collect in the dependent posterior calyces rather than the renal pelvis, as is the case when the patient is prone. Three studies have performed a direct comparison of prone and supine positioning during PCNL by the same surgeon.[13,14,25] Owing to small sample sizes, no significant difference in transfusion rate was noted by any group. However, when considered together, the transfusion rate for PCNL performed in the supine position was 9.8% versus 3.9% when performed prone (132 and 153 patients, respectively, $p = 0.045$). There were no reported instances of organ injury in any patients. In a review, de la Rosette and coworkers examined the effect of patient positioning, concluding that for obese patients or those with staghorn calculi, the prone position was associated with similar bleeding rates, but decreased operative times, and slightly improved stone-free rates compared with the supine position.[33]

Conclusion

Appreciation of the calyceal anatomy, and the ability to choose the appropriate posterior calyx for percutaneous access in the prone position, will allow the operator to perform the procedure with minimal morbidity. Prone-flexed positioning is a simple modification that is well tolerated by the patient and offers significant surgical advantages.

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Disclosure Statement

Dr. A. Andrew Ray—none.
Dr. Dae-Gyun Chung—none.
Dr. R. John D'A. Honey—Consultant, Cook Urological; Consultant, Pluromed, Inc.

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Abbreviations Used

CT = computed tomography
CV = cardiovascular
GMSV = Galdakao-Modified Supine Valdivia
OR = operating room
PCNL = percutaneous nephrolithotomy
PSIC = posterior superior iliac crest

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